International Journal of Advanced Culture Technology Vol.11 No.1 296-305 (2023)
DOI https://doi.org/10.17703/IJACT.2023.11.1.296

IJACT 23-3-34

Analysis of instrument exercise using IMU about symmetry

[1]Yohan Song, [2]Hyun-Bin Zi, [3]Jihyeon Kim, [4]Hyangshin Ryu, [5]Jaehyo Kim*

[1,2,5]School of Mechanical and Control Engineering, Handong Global University, Pohang, Republic of Korea*
[3,4]HIsoLution, 307, 1393, Goyang-daero, Deogyang-gu, Goyang-si, Gyeonggi-do, Republic of Korea
[1]songyohanlearn@gmail.com, [2]apple03130428@gmail.com, [3]jihyeon@hisolution.co.kr, [4]rhs@hisolution.co.kr, [5]jhkim@handong.edu*

Abstract

The purpose of this study is to measure and compare the balance of motion between the left and right using a wearable sensor during upper limb exercise using an exercise equipment. Eight participants were asked to perform upper limb exercise using exercise equipment, and exercise data were measured through IMU sensors attached to both wrists. As a result of the PCA test, Euler Yaw(Left: 0.65, Right: 0.75), Roll(Left: 0.72, Right: 0.58), and Gyro X(Left: 0.64, Right: 0.63) were identified as the main components in the Butterfly exercise, and Euler Pitch(Left: 0.70, Right 0.70) and Gyro Z(Left: 0.70, Right: 0.71) were identified as the main components in the Lat pull down exercise. As a result of the Paired-T test of the Euler value, Yaw's Peak to Peak at Butterfly exercise and Roll's Mean, Yaw's Mean and Period at Lat pull down exercise were smaller than the significance level of 0.05, proving meaningful difference was found. In the Symmetry Index and Symmetry Ratio analysis, 89% of the subjects showed a tendency of dominant limb maintaining relatively higher angular movement performance then non-dominant limb as the Butterfly exercise proceeds. 62.5% of the subjects showed the same tendency during the Lat pull down exercise. These experimental results indicate that meaningful difference at balance of motion was found according to an increase in number of exercise trials.

Keywords: *IMU, Symmetry, Upper Body Exercise*

1. INTRODUCTION

With the recent development of sensor technology, research on physical ability estimation models based on motion measurement using inter-outer body sensors has been actively conducted. For outer body sensor research, camera-based skeleton model estimation and motion analysis [1] is representative. For inter body sensors research, fingertip coordinate analysis using band-type wearable sensors attached to joints [2] is representative. Studies that estimate physical parameters such as the type of exercise, the number of exercises, and exercise time using these sensors are at the center currently [3, 4].

Meanwhile, some studies have proposed a study to evaluate physical ability based on the analysis of exercise balance on the left and right sides of the body. Among the exercise balance analysis studies, studies focusing on diagnosis of patients' conditions, such as looking at symmetrical exercise of scoliosis patients through

Manuscript received: January 31, 2023 / revised: March 2, 2023 / accepted: March 13, 2023
Corresponding Author: jhkim@handong.edu
Tel: +82-54-260-1391, Fax: +82-54-260-1321
School of Mechanical and Control Engineering, Handong Global University, Pohang, Republic of Korea

temperature measurement [5], early diagnosis of neurological disorders [6], and measurement of rehabilitation rate of patients with partial paralysis [7, 8] are mainly studied. In the case of measuring the degree of rehabilitation of the upper limb of the hemiplegia patient, it is measured by setting ability of normal side as a target of maximum recovery of the paraplegic side and comparing them. In the case of exercise balance analysis for the analysis of paraplegia of the lower limb, studies have been proposed to analyze the symmetry of walking in a similar manner of upper limb [9].

However, there are relatively fewer studies on symmetry exercise of the ordinary person compared to studies on patients with hemiplegia. This is because, unlike patients with hemiplegia, the asymmetry of the exercise balance of the ordinary person is not clear. However, there is only a difference in degree, but there is also asymmetry during exercise in the ordinary people, and if left unattended, it can lead to unbalanced muscle development or injury, and targeted muscle development may not be efficient [10]. Therefore, analysis of the symmetry of the ordinary people for multiple exercises will greatly help preventing injury as well as efficient exercise through balanced muscle development.

In this study, inertial sensors attached to both wrists were adopted to evaluate the symmetry of the upper limb movement. This is because Xsens or motion capture used in previous studies have excellent accuracy, but the price of equipment is high, making it difficult and expensive for the ordinary person to access. On the other hand, inertial sensors are easy to carry, can be easily accessed in daily life such as smart watches, and are relatively inexpensive. In addition, experiment was conducted using exercise equipment that are easy to observe due to fixed motion trajectory for more accurate measurement. Butterfly exercise, an exercise in a curved orbit and Lat pull down exercise, an exercise in a linear orbit were adopted as the experiment exercise to obtain the results of various trajectories.

This experiment's objective is to verify symmetricity of upper limb during the upper limb exercise of Butterfly and Lat pull down using wearable sensor. To measure symmetry, the left and right rotation angles of the upper limbs are compared through the inertial sensor, and the measured data gets verified to find main components through the PCA method. After that, to confirm the significant correlation between data and symmetry, the paired-T test is carried out. Subsequently, through the symmetry ratio/index evaluation [11], which can confirm the symmetry of both sides based on one side, study intend to confirm asymmetry in the change of muscle strength over time. By verifying whether it is such meaningful data, this study set objective to check whether it is valid for the ordinary person to check the balance of exercise, and if so, what indicators make a significant difference.

2. RESERCH METHOD

2.1 Data Measurement Method

The upper body exercise equipment used consists of two equipment, Butterfly machine and Lat pull down machine. The exercise equipment uses both hands simultaneously to confirm symmetry among the upper limb exercise equipment.

With the IMU sensor switch facing upward and fingers, the sensor is attached to both wrists to proceed with exercise [12]. The reason why the sensor is mounted on the wrist is to compare the amount of rotation. The measurement frequency is 50 Hz. An experiment was conducted on a total of 15 people, 9 male and 6 female.

Experiment is largely divided into two procedures. The first step is a direct 1RM measurement for identifying the experimenter's motor ability. Starting with the initial weight of 5 kg, increased 5 kg per each step until it is difficult for participants to exercise. Then derived 1RM data when limit was reached. The second experiment step is data extraction for identifying symmetry. According to NSCA – CPT Muscular Endurance

Exercise standard (Load is less than 67% of 1RM / reps over 12 / set 2-3 / break time over 1min) [13], 3 sets are performed 15 times for two exercises at 50% load of 1RM. The break time between exercises was given 5 minutes.

2.2 Data processing

2.2.1. Euler

The data was converted from quaternion to Euler and used. Calibration was performed on the Euler 3 axis to determine the difference in the amount of rotation. The characteristics used are mean, peak to peak, and period. A total of 14 people's data were used.

2.2.2. Gyro

To compare both limb's gyro data from sensor, total of 9 participants' data was used for Butterfly exercise and 8 was used for Lat pull down exercise. Lat pull down was given 8 data due to corruption of single participant's data during measurement.

The sensor's raw data was converted through FFT to output a power spectrum, which was used to analyze the noise and dominant frequency components of the data. Through analyzing power spectrums of each participants' exercise data, dominant frequency values were calculated. To preserve the target waveform and to filter out noise and offset value., minimum cut-off frequency values from each case. For Butterfly exercise, minimum frequency value of 0.295 Hz came out and 0.555 Hz for Lat pull down. To give enough margin, 0.25 Hz and 0.5 Hz was selected. To prevent the left and right data from being partially omitted from the experimental measurement, primary raw data was output through an interpolation process comparing data length of one another.

It was ideal to measure the Euler angle in order to analyze data in a general three-dimensional space, but there was a problem that caused problems such as gimbal lock. To avoid this problem, this experiment was conducted using a gyro value, not a Euler angle. Since measured raw data is an angular velocity value, it was necessary to integrate it once to know the angle value. Therefore, trapezoidal integration was performed on the received raw data. The integrated value was passed through the high-pass filter based on the cutoff frequency from filtering process.

From the extracted data, the values of the lower peak and the upper peak were obtained, and the difference in the values was considered as the actual moving range of motion (ROM). In consideration of the offset error of the start and end of the exercise that exists due to the characteristics of the machine-based exercise, the start and end data were removed from each exercise set data.

2.3 Analysis Method

2.3.1 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is a method of finding lower dimensional data that is most similar to the original high-dimensional data when given a high-dimensional dataset.

In this study, the values of Euler's Roll, Pitch, and Yaw and the values of x, y, and z of Gyro are analyzed through PCA, respectively, and used to determine the values used as the main components.

The left and right sides were analyzed separately, and the result of the sum of the first and second dimensions exceeding 80% was accepted.

2.3.2 Paired t-test

Paired t-test is used to see the difference between the same groups. To use the analysis method, it is necessary to be able to pair the data of the two groups. In this study, it is used to determine whether there is a significant difference in the rotation value of the dominant hand and non-dominant hand.

The null hypothesis is having an average of zero differences between dominant and non-dominant hand. In other words, the two groups are the same. For this analysis, if p is less than 0.05, the null hypothesis is ignored, leading to a conclusion that the difference between the two groups is significant [14, 15].

2.3.3 Symmetry value test

Symmetry evaluation formulas from preceding research was used to evaluate the symmetry of subject. Inside formula, since preceding research mainly focused on evaluation of stroke patients, it was necessary to change the variable from linear velocity to angular velocity in order to evaluate the angular values measured from participants in this experiment. For symmetry ratio formula, if result value is lower than 1.0, it means that more rotational performance was made on dominant limb than undominant limb. In symmetry index formula, result value lower than 0.0 has the same meaning as symmetry ratio formula.

$$Symmetry\ Ratio = \frac{\theta_{undominant}}{\theta_{dominant}} \quad (1)$$

$$Symmetry\ Index = \frac{\theta_{undominant} - \theta_{dominant}}{0.5*(\theta_{undominant} + \theta_{dominant})} * 100\% \quad (2)$$

3. EXPERIMENTAL RESULT

3.1 Principal Component Analysis (PCA)

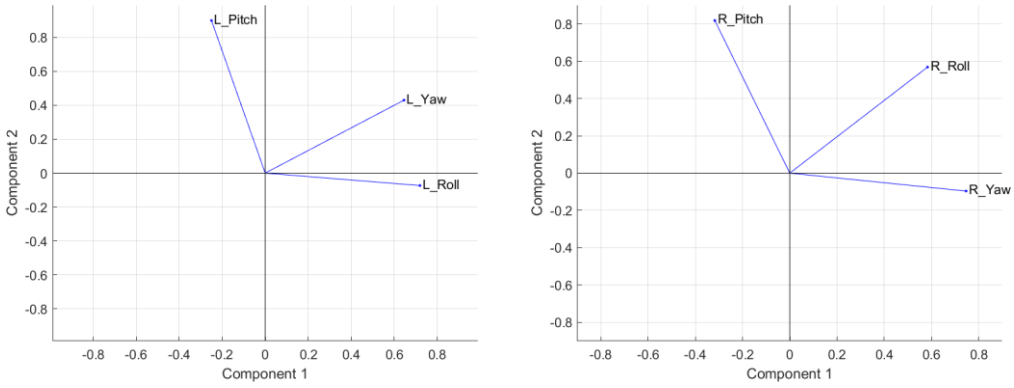
3.1.1 Butterfly

Table 1. PCA result of Euler and Gyro at Butterfly (Unit: %)

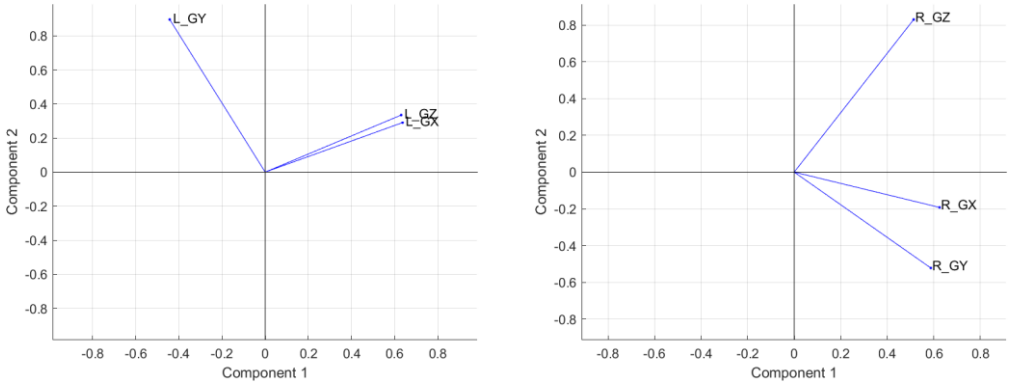
Dimension	Euler		Gyro	
	Left	Right	Left	Right
1	48.24	42.85	72.98	72.71
2	34.76	36.16	23.68	19.98

Table 2. PCA result values of Euler and Gyro at Butterfly

Side	Dimension	Euler			Gyro		
		Roll	Pitch	Yaw	X	Y	Z
Left	1	0.72	-0.25	0.65	0.64	-0.44	0.63
	2	-0.07	0.90	0.43	0.29	0.90	0.34
Right	1	0.58	-0.32	0.75	0.63	0.59	0.51
	2	0.57	0.82	-0.10	-0.19	-0.52	0.83



(a) Euler Left *(b) Euler Right*



(c) Gyro Left *(d) Gyro Right*

Figure 1. PCA results of Euler and Gyro at Butterfly

As a result of PCA analysis, the main components that should be considered significantly in Butterfly exercise by considering more weight on dimension 1 are the Yaw(Left: 0.65 Right: 0.75), Roll(Left: 0.72, Right: 0.58) values of Euler, and X(Left: 0.64, Right: 0.63) values of Gyro.

3.1.2 Lat pull down

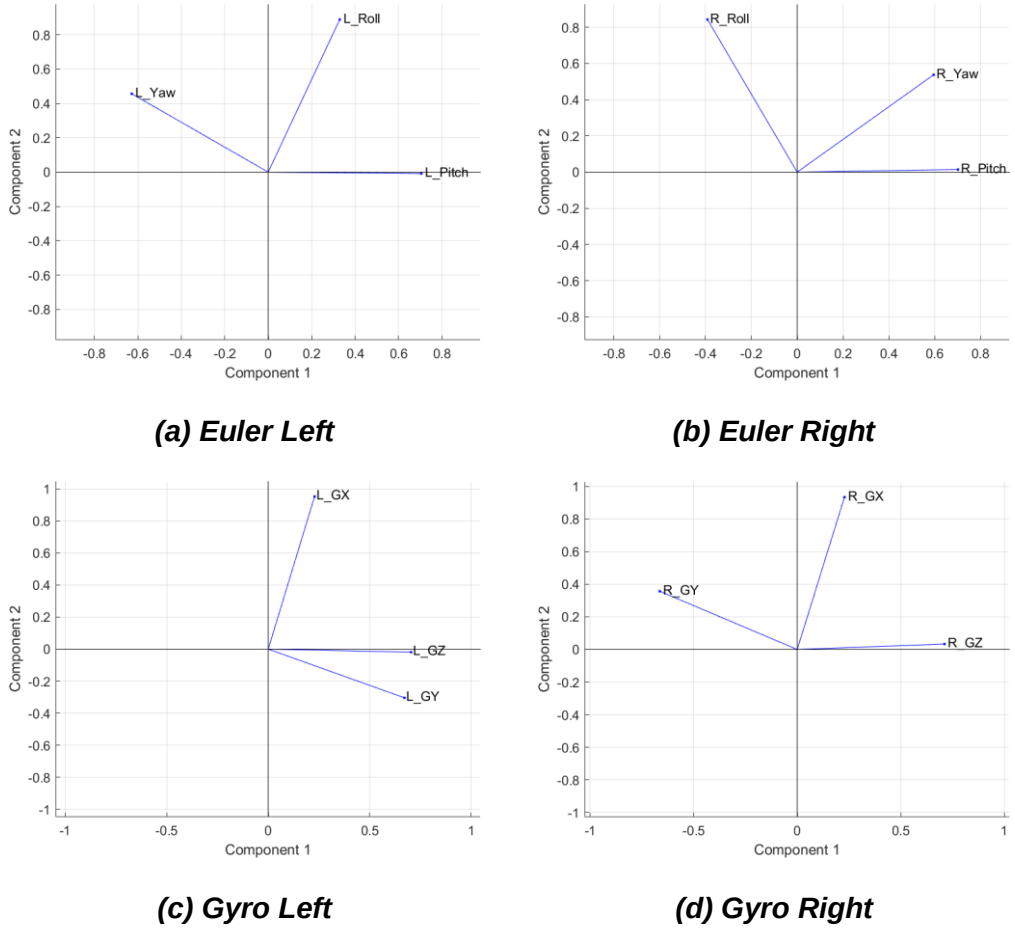
As a result of PCA analysis, the main components that should be considered significantly in Lat pull down exercise by considering more weight on dimension 1 are the Pitch(Left: 0.70, Right: 0.70) values of Euler and Z(Left: 0.70, Right: 0.71) values of Gyro.

Table 3. PCA result of Euler and Gyro at Lat pull down (Unit: %)

Dimension	Euler		Gyro	
	Left	Right	Left	Right
1	57.43	54.98	58.36	55.95
2	33.04	32.68	33.00	34.01

Table 4. PCA result values of Euler and Gyro at Lat pull down

Side	Dimension	Euler			Gyro		
		Roll	Pitch	Yaw	X	Y	Z
Left	1	0.33	0.70	-0.63	0.23	0.67	0.70
	2	0.89	-0.01	0.46	0.95	-0.30	-0.02
Right	1	-0.39	0.70	0.60	0.23	-0.66	0.71
	2	0.84	0.01	0.54	0.93	0.36	0.03



(a) Euler Left ***(b) Euler Right***

(c) Gyro Left ***(d) Gyro Right***

Figure 2. PCA results of Euler and Gyro at Lat pull down

3.2 Paired t-test

3.2.1 Butterfly

The characteristic that the rotational of the dominant hand and the non-dominant hand is significantly different is the Yaw - Peak to Peak value, which has value smaller than significance level of 0.05.

Table 5. Paired t- test result of Butterfly

Angle	Feature	Mean	Standard Deviation	Standard Error Mean	Significance (2-Tailed)
Roll	Mean	0.01890	0.27074	0.04036	***0.642***
	Peak to Peak	-0.04314	0.31033	0.04624	***0.356***
Pitch	Mean	-0.16060	0.08362	0.01246	***0.400***
	Peak to Peak	0.01562	0.01032	0.01539	***0.315***
Yaw	Mean	0.01345	0.08850	0.01334	***0.319***
	Peak to Peak	0.03701	0.08960	0.01350	***0.009***
	Period	0	2.64715	0.39414	***1.000***

3.2.2 Lat pull down

Table 6. Paired t- test result of Lat pull down

Angle	Feature	Mean	Standard Deviation	Standard Error Mean	Significance (2-Tailed)
Roll	Mean	0.27782	0.16051	0.02752	***0.000***
	Peak to Peak	0.03509	0.12854	0.02204	***0.121***
Pitch	Mean	0.00146	0.11707	0.01828	***0.936***
	Peak to Peak	0.02782	0.24470	0.38215	***0.471***
Yaw	Mean	0.02075	0.21748	0.03395	***0.000***
	Peak to Peak	0.01407	0.09286	0.14503	***0.338***
	Period	2.83352	1.75299	0.30063	***0.009***

The characteristic that the rotational of the dominant hand and the non-dominant hand is significantly different is the Roll – Mean, Yaw – Mean, Period value, which has value smaller than significance level of 0.05.

3.3 Symmetricity test

3.3.1 Butterfly

Table 7. Butterfly Symmetry index & ratio result

Subject	Symmetry Index (Unit: %)			Symmetry Ratio		
	1st Set Initial Rep	3rd Set Last Rep	Value Difference	1st Set Initial Rep	3rd Set Last Rep	Value Difference
1	5.34	-2.40	7.74	1.05	0.98	0.07
2	3.14	-13.04	16.18	1.03	0.88	0.15
3	3.11	-4.16	7.27	1.03	0.96	0.07
4	2.96	-8.12	11.08	1.03	0.92	0.11
5	-1.54	-2.54	1	0.98	0.97	0.01
6	-2.03	3.93	-5.96	0.98	1.04	-0.06
7	13.94	-6.27	20.21	1.15	0.94	0.21
8	-7.83	-12.91	5.08	0.92	0.88	0.04
9	-1.37	-12.82	11.45	0.99	0.88	0.11

As a result of the experiment, the index and ratio analysis result at table 7 above showed that 89% of the total subjects tended to maintain the performance of the dominant arm than that of undominant arm over time. This result shows that the exercise balance between the subject's dominant and non-dominant limb was shaken or collapsed as the number of exercise trials accumulates.

3.3.2 Lat pull down

Table 8. Lat pull down Symmetry index & ratio result

Subject	Symmetry Index (Unit: %)			Symmetry Ratio		
	1st Set Initial Rep	3rd Set Last Rep	Value Difference	1st Set Initial Rep	3rd Set Last Rep	Value Difference
1	-10.97	-25.73	14.76	0.90	0.77	0.13
2	-29.50	1.75	-31.25	0.74	1.02	-0.28
3	-17.77	-21.51	3.74	0.84	0.81	0.03
4	38.94	20.38	18.56	1.48	1.23	0.25
5	-21.73	-15.60	-6.13	0.80	0.86	-0.06
6	8.58	33.51	-24.93	1.09	1.40	-0.31
7	-18.39	-60.45	42.06	0.83	0.54	0.29
8	14.43	11.31	3.12	1.16	1.12	0.04

In case of Lat pull down, the index and ratio analysis result at table 8 above showed that 62.5% of the total subjects tended to maintain the performance of the dominant arm than that of undominant arm over time. This result shows a similar result of Butterfly exercise, but it has lower tendency than that.

4. DISCUSSION

Through this experiment, obtained result shows that meaningful difference of exercise balance occurred during repetitive exercise process, and could be more significant if higher weight is given to the subject. However, excessive weight setting is usually the cause of excessive exercise. Through the indicators obtained through this experiment, it can be used as an indicator to verify and measure what weight is appropriate for one's exercise. This could also be applied to determine the appropriate weight for balanced muscle stimulation and muscle development on symmetric sides.

On the other hand, there are three limitations due to the experiment and data selection process. First, in addition to the mean and peak values, there may be parameters that can describe the data and indicate differences. Second, all subjects are right-handed, understaffed, and the weight applied during the experiment does not cause sufficient fatigue, which can lead to inaccuracies in measurements. Third, unlike Butterfly exercise equipment that allows both arms to move independently, Lat pull down machines have a structure in which both hands hold a rod connected in a straight line, so it is possible that the movement of one hand affected the other.

To improve these problems, future studies recruit more experimental participants, including left-handed people, to add controls in future experiments. Furthermore, more diverse data indicator analysis will be conducted. Also, unlike let pull-downs, studies are needed on motion that can perform two-handed movements independently or on how data can be extracted considering these interferences.

5. CONCLUSION

Through the Paired t-test, it was possible to confirm the parameter whose difference between left and right was significant, and through the Symmetry Index and Symmetry Ratio, the numerical asymmetry of dominant and undominant arm over time could be confirmed. This result shows that asymmetry could be found from ordinary person during exercise. The further goal is to confirm the significant difference between symmetry and the corresponding value in other movements through follow-up studies. Also, we intend to analyze the tendency of the collapse of exercise balance resulted by subject's muscle strength through adjustment of 1RM weight in the future.

By analyzing the symmetry of both sides, this research can be applied to fields such as assisting the equal growth of muscles in the field of fitness and well-being.

ACKNOWLEDGEMENT

This study was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education (2020R1I1A3A04038203).

REFERENCES

[1] Wang, J. "Motion recognition based on deep learning and human joint points." Computational Intelligence and Neuroscience, 2022. https://doi.org/10.1155/2022/1826951

[2] Chen, Weiya, et al. "A survey on hand pose estimation with wearable sensors and computer-vision-based methods." Sensors, Vol. 20, Issue. 4, No. 1074, 2020. https://doi.org/10.3390/s20041074

[3] Chudecka, Monika, and Lubkowska. "The use of thermal imaging in the evaluation of the symmetry of muscle activity in various types of exercises (symmetrical and asymmetrical)." Journal of human kinetics, Vol. 49, Issue. 1, pp. 141-147, December 2015. https://doi.org/10.1515/hukin-2015-0116

[4] Soro, Andrea, et al. "Recognition and repetition counting for complex physical exercises with deep learning." Sensors, Vol. 19, Issue. 3, No. 714, 2019. https://doi.org/10.3390/s19030714

[5] Vutan, Ana-Maria, and Lovasz, E.C, "Evaluation of Symmetrical Exercises in Scoliosis by Using Thermal Scanning." Applied Sciences, Vol. 12(2), pp. 5-8, January 2022. https://doi.org/10.3390/app12020721

[6] Procházka, Aleš, et al. "Motion symmetry evaluation using accelerometers and energy distribution." Symmetry, Vol. 11(7), pp. 1-12, 2019. https://doi.org/10.3390/sym11070871

[7] Patterson, Kara K., et al. "Evaluation of gait symmetry after stroke: a comparison of current methods and recommendations for standardization." Gait & posture, Vol. 31, Issue. 2, pp. 241-246, February 2010. https://doi.org/10.1016/j.gaitpost.2009.10.014

[8] Siebers, Hannah Lena, et al. "Comparison of different symmetry indices for the quantification of dynamic joint angles." BMC Sports Science, Medicine and Rehabilitation, Vol. 13, No. 130, pp. 1-11, October 2021. https://doi.org/10.1186/s13102-021-00355-4

[9] Gurchiek, Reed D., et al. "Remote gait analysis using wearable sensors detects asymmetric gait patterns in patients recovering from ACL reconstruction." 2019 IEEE 16th International Conference on Wearable and Implantable Body Sensor Networks (BSN). IEEE, 2019. https://doi.org/10.1109/BSN.2019.8771038

[10] Horbacz, A., Majherová, M., & Perečinská, K., "Posture and muscle imbalance in young tennis players", Scientific Review of Physical Culture, Vol.3, No.4, pp. 33~38. 2013

[11] Błażkiewicz, Michalina, Ida Wiszomirska, and Andrzej Wit. "Comparison of four methods of calculating the symmetry of spatial-temporal parameters of gait." Acta of bioengineering and biomechanics, Vol. 16

No. 1, 2014. http://dx.doi.org/10.5277/abb140104

[12] Bakhshi, Saba, Mohammad H. Mahoor, and Bradley S. Davidson. "Development of a body joint angle measurement system using IMU sensors." 2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE, 2011. https://doi.org/10.1109/IEMBS.2011.6091743

[13] Baechle, T. R., R. W. Earle, and Thomas R. Baechle. NSCA's essentials of personal training. Human Kinetics, 2004.

[14] Amirhamzeh, M. M. R., Chant, H. J., and Campbell, W. B. “A comparative study of treadmill tests and heel raising exercise for peripheral arterial disease” European journal of vascular and endovascular surgery, Vol. 13, Issue. 3, pp. 301-305, March 1997. https://doi.org/10.1016/S1078-5884(97)80102-5

[15] Rasti, E., Rojhani-Shirazi, Z., and Sobhan, M. R. “Effects of whole body vibration with exercise therapy versus exercise therapy alone on flexibility, vertical jump height, agility and pain in athletes with patellofemoral pain: a randomized clinical trial”. BMC Musculoskeletal Disorders, Vol. 21, No. 705, pp. 1-9, October 2020. https://doi.org/10.1186/s12891-020-03732-1